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REVIEW OF RECENT DEVELOPMENTS

Nickel- and Cobalt-Base Alloys

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The information summarized in this review covers research now in progress and new developments in the field of nickel-base and cobalt-base alloys as disclosed in documents received by the Defense Metals Information Center during the past 6 months.

NICKEL-BASE SUPERALLOY

Research sponsored by NASA at the TRW Equipment Laboratories is directed toward the development of a superior cast nickel-base superalloy for turbine blading.(1) The maximum strengthening effects produced by gamma-prime precipitation (Ni_3Al), solid solution of refractory and precious metals, and the formation of stable carbides are to be combined in a single alloy. Target properties desired include a 3,000-hr stress-rupture life at 1875 F and 15,000-psi load.

Work completed thus far covers an evaluation of the effect of molybdenum, tungsten, and tantalum variations in three nickel-base superalloy systems at different aluminum-plus-titanium levels. Tantalum was found to be more beneficial to high-temperature stress-rupture properties than were molybdenum or tungsten. The best alloys developed to date compare favorable with the best commercial alloys. Statistical and metallographic studies of the alloys suggest the following base composition alloy for further study:

C	Co	Cr	Mo	W	Ta
0.13	10.0	10.0	2.0	5.5	3.0

Ti	B	Zr	Ni
1.0	0.02	0.03	Bal

In future work, the aluminum content is to be varied, and the effects of columbium, vanadium, hafnium, rhenium, and ruthenium additions are to be evaluated.

NICKEL-BASE SHEET ALLOY

Work is in progress at the Advanced Engine and Technology Department of General Electric Company to develop a weldable nickel-base sheet alloy having a strength/weight ratio of 250,000 in., a yield strength of 150,000 psi, and a stress-rupture life of 1,000 hr at 75,000-psi stress, both at 1400 F.(2) The material is for potential application in fabricated aerospace vehicles and propulsion systems.

Three series of alloys have been evaluated. These alloys are nickel-base strengthened by gamma-prime precipitation and the solid solution of conventional alloying elements, or of rhenium and ruthenium. Yield strengths in excess of 18,000 psi at 1400 F were developed in some of the alloys containing conventional solid-solution-strengthening elements, but the ductilities and rupture lives were low. The alloys containing rhenium and ruthenium had low strength and ductility; no satisfactory explanation for this behavior was found. A fourth series of alloys is to be prepared to explore the aluminum, titanium, and columbium ranges. Molybdenum and tungsten contents are to be varied, and the effects of carbon, boron, and cobalt investigated.

WROUGHT NICKEL-BASE SUPERALLOY FOR TURBINE WHEELS

Universal-Cyclops Steel Corporation is working on the development of an ultra-high-strength nickel-base superalloy for wrought turbine-wheel applications that use refractory-metal blades.(3) Target properties at 1600 F include 150,000-psi tensile strength and 100-hr stress-rupture life at 70,000 psi. Adequate oxidation resistance and room-temperature ductility are also required. These target properties represent a significant increase over the properties of the best current superalloys.

Several groups of experimental alloys that combine solid-solution strengthening with strengthening produced by the precipitation of stable intermetallic compounds or carbides have been investigated. The combination of tensile and stress-rupture properties of some of these alloys is better than similar properties of wrought commercial superalloys. Extruded experimental alloys having tensile strengths of 110,000 psi at 1600 F have also been produced. The design, fabrication, and testing of additional alloys is in progress.

DISPERSION-STRENGTHENED NICKEL- AND COBALT-BASE ALLOYS

Sylvania is investigating the use of stable, well-dispersed refractory particles, in place of soluble precipitates, as an effective mechanism for strengthening and extending the operating temperature of nickel- and cobalt-base alloys above 2200 F.(4) Such alloys are produced by powder metallurgy. The technique of selectively reducing intimately mixed oxides prepared by atomizing and drying a solution of the components was found to be more successful than the technique of coating dispersoid particles with the matrix alloy by vapor deposition. Hot pressing, hydrogen sintering, and powder rolling were evaluated for the consolidation of Ni-15Mo, Ni-20Cr, cobalt, and Co-15Mo powders containing thoria. It was possible to control the thoria particle size during consolidation, and densities above 90 percent were produced. The exact conditions for successful rolling of the Ni-15Mo-4ThO_2 powder into sheet were determined. This sheet material had tensile strengths up to 150,000 psi at room temperature, 62,000 psi at 1400 F, and 21,000 psi at 1800 F. At higher temperatures the strength fell to that of TD Nickel, but optimum properties were probably not obtained in the present work. Future work will include the refinement of the powder processing, consolidation, and working. The complete physical and mechanical properties of the best alloys are to be determined.

DISPERSION-STRENGTHENED COBALT-BASE ALLOYS

The effect of ultrafine thoria dispersions on the properties of cobalt-base alloys is being investigated at Du Pont.(5) Co-ThO_2, Co-30Ni-ThO_2, and Co-10Fe-ThO_2 alloys have been studied, and preliminary work is in progress on Co-Cr-ThO_2 and Co-Ni-Cr-ThO_2 compositions. Thoria contents range from 0.5 to 4.0 volume percent.

Powders produced by a coprecipitation process are compacted, and sintered to produce billets that are extruded and swaged into bars. The working temperatures are varied with the compositions. Thoria-particle growth during processing is negligible and the particle size ranges from 8 to 14 millimicrons.

The dispersion-strengthened cobalt-base alloys all show excellent high-temperature strength and ductility. For example, the Co-30Ni-2ThO_2-0.1Zr alloy after working 94 percent has a tensile strength of 28,700 psi, a yield strength of 26,600 psi, and 6 percent elongation at 2000 F. The stress-rupture life is 19 hr for a 20,000 psi stress at this temperature.

The addition of a fine thoria dispersion to cobalt was found to increase both the sluggishness and the hysteresis of the allotropic transformation at 785 F of the hexagonal-close-packed structure to the face-centered cubic structure.

The addition of 20 to 22 percent chromium improves the oxidation resistance of the alloys to a marked extent. Both the Co-20Cr-2ThO_2 and the Co-20Ni-22Cr-2ThO_2 alloys show a weight loss of less than 1 mg/cm^2 after 100 hours of cyclic exposure to temperatures of 2000 and 2200 F.

Further work is to be directed toward a better understanding of the Co-Cr-ThO_2 and Co-Ni-Cr-ThO_2 systems.

STUDY OF DISPERSION-STRENGTHENED ALLOYS PRODUCED BY SLIS TECHNIQUES

Nuclear Metals has worked for some time on dispersion-strengthened uranium and other alloys in which the precipitate particles are formed by "splattercooling" the liquid alloy.(6) The name SLIS applied to such alloys implies that the precipitate is soluble in the liquid state but insoluble in the solid state.

The following procedure is used for preparing SLIS alloys. An alloy melted in an inert gas or vacuum is "cross-jet splattercooled" by pouring into a high-velocity gas stream. This atomizes the metal and impinges it against a rotating copper disk for rapid cooling. The fine particles are then consolidated by powder-metallurgy techniques to produce solid alloys.

The application of the SLIS technique to nickel-base alloys is to be investigated. Preliminary research centered about a study of the solid solubility and thermal stability of several nickel compounds.

NEW CASTING TECHNIQUE FOR SUPERALLOYS

Previous improvements in the creep resistance of cast-superalloy gas-turbine components have been made at the expense of ductility, thermal-shock resistance, and oxidation resistance.

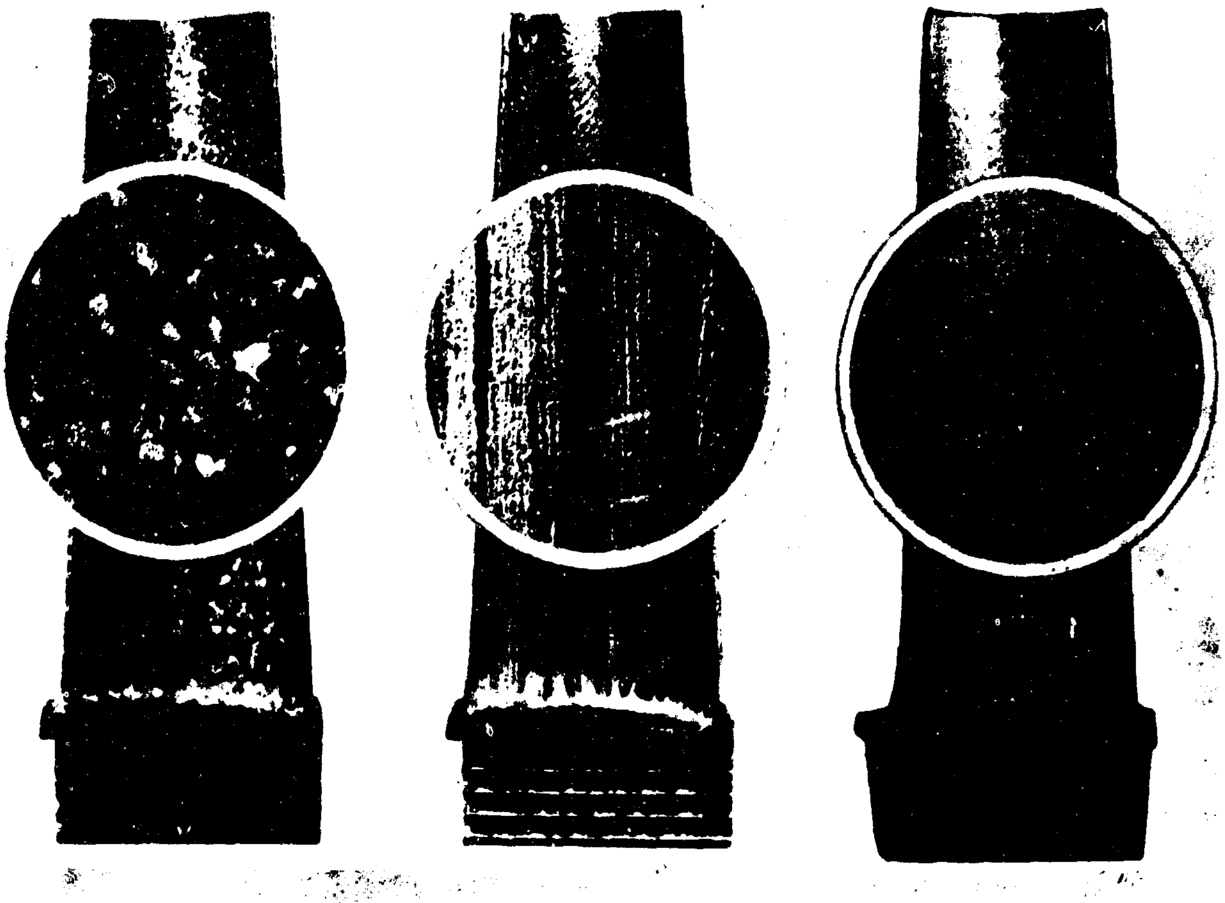
Pratt and Whitney has perfected a precision casting technique, based on directional solidification, which overcomes the above-mentioned difficulties.(7) This technique produces columnar grains parallel to the major axis of the casting, thus eliminating transverse grain boundaries.

Accelerated endurance tests made in experimental gas turbines show that uncoated Mar M-200 alloy blades cast by the directional solidification technique outlast coated blades of the same alloy cast in the conventional manner. Laboratory tests also show the directionally solidified castings to have superior strength and ductility at both room and elevated temperatures.

In continuing research, Pratt and Whitney has invented a process for making single-crystal jet-engine castings.(8) Material produced by this new casting process is judged to be four times as durable as conventionally cast material and to have exceptional shock resistance. The material is to be tested in engines in the near future.

According to Pratt and Whitney, the new casting process will not halt production of castings made by the directional solidification process. At present, vanes made by the directional solidification process have accumulated 26,000 hours of flight testing.

Figure 1, from left to right, shows the equiaxed grain structure of a conventionally cast turbine blade, the columnar structure of a directionally solidified turbine blade, and the structure of the newly developed single-crystal blade. The absence of grain boundaries in the latter blade will be noted.



Conventionally Cast — Directionally Solidified — Single Crystal

FIGURE 1. STRUCTURES OF CAST TURBINE BLADES

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(7) Piearcey, B. J., and Versnyder, F. L., "A New Development in Gas Turbine Materials - The Properties and Characteristics of PWA 664", Pratt and Whitney Aircraft, North Haven, Conn., AIAA Paper No. 65-742 (November, 1965).

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